3.9 Microwave assisted Plasma Generation for Exhaust Gas Treatment

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Abstract
Microwave treatment of exhaust gases is an alternative technique to remove disturbing components. This investigation proves the principle feasibility of this microwave technique in a resonator (Figs. 3.9-1 and 3.9-2).

Introduction
Key advantages of this technique are:

- Affordability and availability of used parts
- Simple design
- Constant emission reduction power (no filter characteristic)
- No regeneration required
- No mechanical wear and tear of the apparatus
- No increased exhaust back pressure as with filters. Therefore, lower fuel consumption

Disadvantage:

- High power of approximately 1 kW necessary, which may be reduced under certain circumstances. However, this energy could be recuperated in heat exchangers

Operating mode
The applied technique uses high pressure plasma which is generated by a velocity modulated tube (magnetron) visualized in Fig. 3.9-1 (1).

Calculation of the resonator design
Background of the present design is the standard-waveguide WR-340 with measures a=90, 42 mm and b=47,24 mm, Fig. 3.9-1 (2).

In this case, the lower cut-off frequency f10 of the fundamental mode H10 is

$$f_{10} = \frac{c}{2a} = \frac{3 \cdot 10^8 m}{2 \cdot 0{,}09\, m \cdot s} = 1{,}666\overline{}\, GHz$$

The wavelength λ10 of the mode H10 results in

$$\lambda_{10} = \frac{c}{f_{10}} = \frac{3 \cdot 10^8 m \cdot s}{1{,}666\overline{}\, GHz \cdot s} = 0{,}180\, m.$$

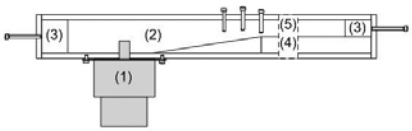

Abb. 3.9-1: *Resonator*

Abb. 3.9-2: *Resonator*

Abb. 3.9-3: *Test Setup in the High Frequency Laboratory of the University of Appl. Sci. Offenburg*

The wavelength λH in the waveguide yields to

$$\lambda_H = \frac{\frac{c}{f}}{\left(1-\left(\frac{c \cdot \lambda_{10}}{c \cdot \lambda}\right)^2\right)^{0,5}} = \frac{\frac{3 \cdot 10^8 m}{2{,}457\, GHz \cdot s}}{\left(1-\left(\frac{3 \cdot 10^8 m \cdot s \cdot 1{,}666\overline{}\, GHz}{3 \cdot 10^8 m \cdot s \cdot 2{,}457\, GHz}\right)^2\right)^{0,5}} = 0{,}1662\, m.$$

An inner length of 2λH is chosen to gain a resonance within the plasma zone. Adjustment of the resonance is achieved with the pushers on both sides, Fig. 3.9-1 (3). Approximately 800 W are applied in these investigations.

Test setup (Fig. 3.9-2)
The tests took place in an anechoic chamber. For safety reasons, an electromagnetic shielding around the plasma zone, Fig. 3.9-1 (5) is mounted.

Consequently, only a little and a harmless amount of microwave energy was emitted from the resonator. A 25 kV spark gap Fig. 3.9-1 (4) is applied for reliable plasma ignition.

Soot particles were generated by an under-stoichiometric burning flame, Fig. 3.9-3 (1). The exhaust gas was aspirated by a carrier gas, Fig. 3.9-3 (2) in a venturi nozzle, Fig. 3.9-3 (3).

The soot content with and without the micro wave treatment was measured by PIERBURG BOSCH smoke degree-meter Fig. 3.9-3 (4). The treated soot concentration was found to be approximately 5,8 g m3.The generated plasma was carried away at the high volume flows of the exhaust gas. This problem could be solved by magnetic retention of the plasma. The induced microwave energy could be increased dramatically by concentration through magnetic fields in the plasma zone.

Results

The results can be summarized by the following statements:

- Existing designs of similar resonators could be simplified strongly.
- The soot content was reduced up to 69 % (Table 1 and Fig. 3.9-4).
- The waste energy could be recuperated in heat exchangers downstream – thus, the dis-advantage of the necessary high energy is partly compensated.
- The micro wave gas treatment offers several applications apart of the diesel exhaust. For example, treatment of toxic gases is also feasible.

	Magnetron	
	Off	On
Bosch numbers BN	5,9	2,2
	5,7	2,7
	5,8	2,3
	5,8	2,2
Average value BN	5,8	2,35
Concentration g*m-3	0,5044	0,1557

Table 1: *Soot reduction*

Outlook

The path for a competitive technical application is still long. An exception may be the treatment of toxic gases which needs further experimental investigations. The usage for the exhaust gas aftertreatment of diesel engines needs further simplification of the resonator and effective magnetic retention of the plasma to reduce the operating power and to increase the efficiency.

Acknowledgement

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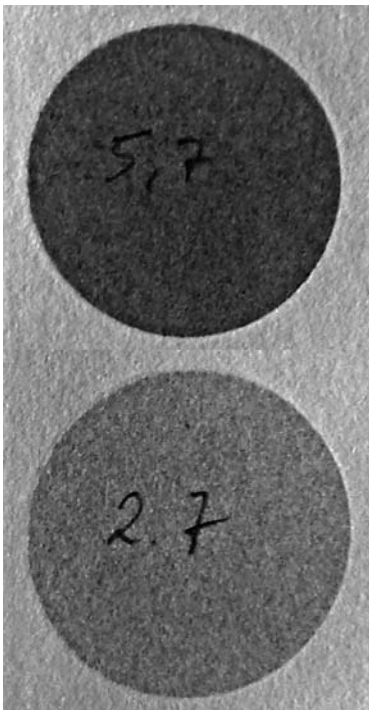

Abb. 3.9-4: *Blackened filter without microwave treatment (1), with (2) Magnetron turned on*